Zhang et al. Heritage Science (2023) 11:269
https://doi.org/10.1186/s40494-023-01101-4

Heritage Science

RESEARCH

Open Access

On conservation of world heritage Beijing-Hangzhou grand canal for enhancing cultural ecosystem services

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Abstract

The Beijing-Hangzhou Grand Canal carries unique social and cultural significance as a world cultural heritage, but with the acceleration of global urbanization, it has potentially severe environmental risks under continuous anthropogenic disturbances. Therefore, to protect the ecological and cultural values of the Grand Canal, it is necessary to assess the corresponding relationship of water quality to land use and the perception of ecosystem services that focus on cultural ecosystem services (CES). This study aims to analyze the water quality response to land use in the Beijing-Hangzhou Grand Canal, describe the land use types closely related to water quality, and propose corresponding management strategies for enhancing CES. This study investigated the impacts of land use structure and landscape pattern on water quality by calculating the correlation between land use structure and landscape pattern indices and water quality in buffer zones of different distances on both sides of the canal. The results show that green land dominates the land use structure and can effectively reduce water pollution in the canal. On the other hand, urban impervious surfaces showed a significant positive correlation with pollution contributing to low water quality. We accessed the impact of water quality on the perception of CES in the Beijing-Hangzhou Grand Canal and proposed optimization strategies for promoting CES. Both content analysis and thematic analysis were applied to analyze the impact of the water environment quality of the Beijing-Hangzhou Grand Canal on the perception of CES. We found that the perceptions of CES along the Beijing-Hangzhou Grand Canal are associated with the public's opinions on its cultural heritage services and artistic inspiration services. The perceptions of CES are closely related to the quality of the water environment and riparian greenness, which affect the values of cultural heritage and conservation of the Beijing-Hangzhou Grand Canal.

Keywords Land use, Landscape patterns, Riparian greenness, Water quality, Perception, Thematic analysis

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Introduction

World Cultural Landscape Heritage (WCLH), as a particular category of World Heritage, results from the joint efforts of a specific geographic environment and human beings and is recognized by UNESCO and the World Heritage Committee as irreplaceable and rare [1]. However, many historical and cultural heritage sites around the world are being seriously damaged, and serious problems such as "urbanization," "commercialization," "artificiality," and "heritage islands" have emerged [2]. The Beijing-Hangzhou Grand Canal is one of the most extraordinary hydraulic engineering projects in the history of human civilization and has had a profound impact on the economic development of cities and social and cultural civilization in China through the regions it flows. As a vast system of inland waterways, the Beijing-Hangzhou Grand Cana stretches 1794 km from Beijing in the north to Hangzhou in the south. Built in sections from the fifth century BCE., it was the world's most extensive civil engineering project before the Industrial Revolution. The Grand Canal was inscribed on the UNESCO World Heritage List at the 38th session of the World Heritage Committee in 2014. However, at the same time, as the route along the Beijing-Hangzhou Grand Canal has traditionally been a densely populated and industrially distributed area, rapid urbanization has also brought many risks and challenges to the protection and management of the Beijing-Hangzhou Grand Canal, which is facing severe problems such as ecological risks of degradation of the aquatic environment as well as the trivialization of the value of the cultural heritage [3]. In recent years, as the protection and transmission of historical and cultural heritage have increasingly emphasized the balance and sustainability of ecological, cultural, social, and economic systems, the conservation value of the Beijing-Hangzhou Grand Canal has gradually gained importance for the cultural ecosystem services it provides to society [4], such as cultural heritage, spirituality, and inspirational inspiration.

Ecological risk refers to the possibility of structural and functional damage to the ecosystem, which will reduce the health, productivity, genetic diversity, economic value, and aesthetic value of the ecosystem at present, impacting its sustainable development in the future [5]. Based on their occurrence characteristics, they can be divided into sudden risks with abrupt impacts (e.g., flooding, leakage of flammable substances) [6] and cumulative hazards with long-term effects (e.g., heavy metal pollution) [7]. The possibility of ecological risk is often closely related to land use change because land cover change caused by land disturbance can alter the structure and function of the ecosystem. Such land use disturbance can affect water quality by influencing the nutrient flues in surface water and thus affect the ecological processes of water bodies.

Land use changes have various environmental effects [8, 9], resulting in various actual or potential ecological risks [10]. For water bodies, land use patterns, including green space, can have a significant impact on the water cycle and the transport of substances, profoundly affecting the concentration of pollutants in surface runoff and the process of pollution formation [11, 12], as well as influencing urban heat-island effects [13]. The Beijing-Hangzhou Grand Canal, a vital freight waterway in China since ancient times, is densely populated along the shoreline. The industry was once significantly developed, with many years of direct sewage discharge history, a large amount of domestic sewage or industrial wastewater directly or indirectly discharged into the canal without treatment, and a considerable amount of heavy metal pollutants accumulated in the bottom mud of the canal which became an intrinsic pollutant that restricts the quality of the overlying water bodies. Meanwhile, with the increase in urbanization, the area of impermeable ground in the city is increasing. When rainfall occurs, the non-point source runoff will wash many pollutants into the river. The continuous input of pollutants into the Beijing-Hangzhou Grand Canal has become an essential potential ecological risk, and its continuous disturbance of water sources and farmland which are the resources that human beings rely on for their survival. These inputs will further become a potential risk that affects human health. Unreasonable land-use structures may contribute to eutrophication and algal growth in water bodies, reducing water quality [14]. Spatial patterns of land use can also affect water quality [15] with pollutants being affected by spatial patterns in their transport and transformation before entering the water body and improper landscape composition and configuration similarly increasing the transfer of nutrients to the water body [16]. The impacts are complex and often related to spatial scale [17]. The impacts of land-use structures and spatial patterns on water quality change as the size of the buffer zone expands, and an optimal buffer zone exists [15]. However, the scale at which land use structures and spatial patterns have the greatest impact on water bodies will vary slightly between water bodies of different characteristics.

Due to historic canals' unique social and cultural significance, maintaining ecosystem functions and promoting ecosystem cultural services are crucial in managing historic canal sustainability [18]. Ecosystem services refer to the benefits provided by nature that directly or indirectly contribute to sustainable human well-being which include provisioning services (e.g., provisioning of food and water), regulating services (e.g., control of floods and disease), cultural services (e.g., spiritual, recreational and cultural benefits), and supporting services (e.g., nutrient cycling to maintain the environment in which life on Earth takes place) [19]. However, in the past management of landmark canals, more consideration has been given to improving their ecological quality, and less attention has been paid to cultural ecosystem services. Cultural Services of Ecosystems (CES) are "the non-material benefits that human beings derive from ecosystems through spiritual life, cognitive development, educational reflection, recreation, and aesthetic experience" [20]. As a type of river landscape, the cultural service benefits of the historical canal ecosystem are closely related to the river's water quality. Roebeling et al. [21] showed that improving the chemical condition of surface water, and in particular the ecological condition of surface water, would have positive marginal benefits, and that improvements in water quality would greatly enhance the perceived value of ecosystem cultural services along the shoreline [21]. Unlike other ecosystem services (provisioning, regulating, supporting services), which regard research methodology, CES must be measured through human behavior and perception [22]. By integrating environmental psychology and landscape aesthetics, landscape perception can be studied deeply, revealing the interaction mechanism between landscape physical features and human perceptual judgment [23]. However, few scholars have explored how different CESs in a given space are perceived. As a UNESCO World Heritage Site, the Beijing-Hangzhou Grand Canal has become a semi-natural mosaic (i.e., through inheritance or being perceived by people as part of the natural and cultural landscape) with time. It has provided additional social and cultural value beyond its original function [24, 25] (Table 1) (Fig. 1). The ecosystem cultural service perception is an essential manifestation of the social and cultural value of the Beijing-Hangzhou Grand Canal. Integrating geospatial data and network review data to identify CES has become a significant trend [26, 27]. A large amount of individual use information (e.g., geographic coordinates, semantic text, emotional communication, etc.) recorded in network review data can be applied to the study of landscape perception by filtering and translating, which, to a certain extent, makes up for the shortcomings of the traditional research methods in data acquisition.

Therefore, in order to highlight the critical conservation value of the Beijing-Hangzhou Grand Canal as a historical and cultural heritage, and to guide the future conservation and management of the Beijing-Hangzhou Grand Canal based on the principles of ecological, cultural and social balance and sustainability, the objectives of this paper are specifically: (1) to reveal the responsive relationship between water quality and land use change, and identify land use types that have a significant impact on water quality; (2) uncovering the impact of water quality on perceptions of ecosystem cultural services and their functioning mechanisms; (3) Based on the above findings, the critical points of the protection and management work of the Beijing-Hangzhou Grand Canal are summarized from the comprehensive perspective of ecological risk response, cultural heritage protection, and corresponding optimization policies are proposed to provide decision-making suggestions for the future management and protection work of the Beijing-Hangzhou Grand Canal, the conceptual framework of the paper is shown in Fig. 2.

Table 1 Representative Resources of Intangible Cultural Heritage of the Suzhou Section of the Beijing-Hangzhou Grand Canal

Categorization	Titles
Traditional techniques	Chinese silk weaving techniques (Suzhou Song Brocade Weaving Technique, Suzhou Woof Weaving Technique), Suzhou Xiangshan Gang Traditional Building Construction Technique, Suzhou Imperial Kiln Gold Brick Making Technique, etc
Folk literature	Pingwang Riddles (traditional Chinese riddle), Wuge Xiqu, etc
Traditional dances	Dang Hu Chuan (Swaying the boat), etc
Traditional arts	Suzhou Lantern Colour, Suzhou Clay Sculpture, Nuclear Carving (Guangfu Nuclear Carving), Suzhou Jade Carving, Bonsai Technique (Suzhou Bonsai Technique), Brick Carving, Suzhou Redwood Carving, Buddha Statue Carving
Folklore	Temple Fair (Jincun Temple Fair), Suzhou Dragon Boat Festival Custom, Marriage custom (marriage custom of fishermen in Taihu Lake), etc
Traditional music	Suzhou Minor, Suzhou Chanting (Tang tune), Jiangnan traditional Chinese stringed and woodwind instruments, etc
Traditional drama	Kunqu Opera, Suzhou Opera, etc
Folk art	Suzhou Pingtan, etc
Traditional sports Recreation, Acrobatics	Jiangnan ship boxing, rocking clippers, etc

Fig. 1 Distribution of World Heritage Sites along the Suzhou section of the Beijing-Hangzhou Grand Canal. In the map: **a** Shantang River is connected to the Grand Canal, one of the main waterways of the Suzhou section of the ancient Grand Canal. There are numerous existing cultural relics and monuments, rich cultural heritage, and well-preserved relevant historical buildings and historical patterns of the neighborhood. **b** Its water system and streets and lanes have preserved the original appearance of the trunk and branch river structure of the waterway system of the city and the double checkerboard pattern of water and land with the river in front and behind the street and parallel streets and rivers, which are shown on ancient maps. **c** China's only well-preserved land and water-parallel historical city gate, with high historical and cultural heritage value. **d** Located on the west bank of the Beijing-Hangzhou Grand Canal, lying north–south between the Grand Canal and Tantai Lake, parallel to the ancient canal, it is one of the ten most famous bridges in ancient China and also the most prolonged and best-preserved large-scale ancient stone bridge with continuous arches in China. **e** It is both an ancient boat-tracker path and a post road, the only remaining ancient boat-tracker road of the Jiangnan Canal, which is of great significance

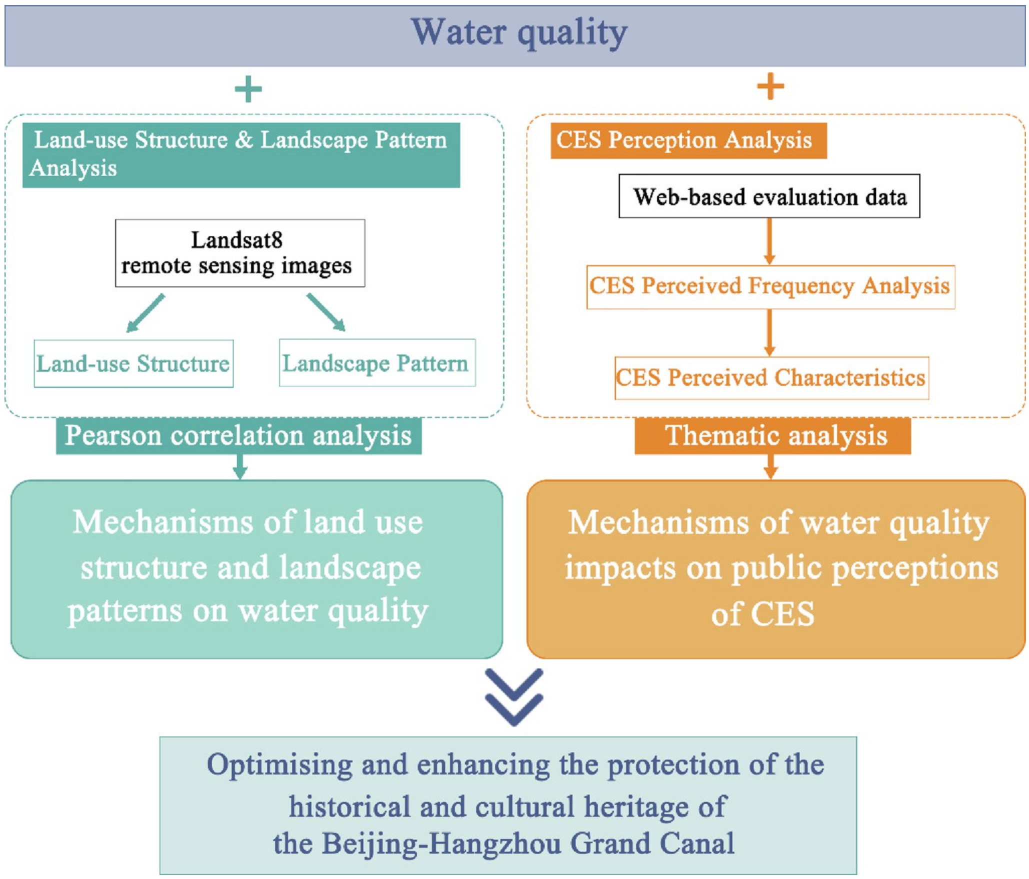

Fig. 2 Conceptual framework for studying the relationship between water quality and Cultural Ecosystem Services (CES)

Methods

Study area overview

The study area is within the 500 m buffer zone of the Beijing-Hangzhou Grand Canal within the Suzhou municipal district. The study area is flat and low-lying with an elevation of 3.0–5.0 m; it has a subtropical monsoonal maritime climate with an average annual temperature of 16–18 ℃ and a yearly precipitation of about 1000–1,400 mm. The Suzhou section of the Beijing-Hangzhou Grand Canal is about 95 km long (the old canal south of the Taipu River is about 13 km long) and crosses several administrative districts in Suzhou (Fig. 3). Suzhou's "one park and three districts" (Suzhou Industrial Park, Suzhou High-tech Zone, Wuzhong Development Zone, and Wujiang Development Zone) are all based on the canal. The development of the canal has provided a unique advantage for the rapid rise of Suzhou's development zones. The ecological conditions and the nature of the land along the river vary significantly from one section to another. The upper reaches in the Gaoxin District and Xiangcheng District are mostly suburban industrial parks with secondary industries as the primary economic industries, with significant industrial and agricultural pollution emissions, high intensity of human interference, and poor water quality. The middle reaches of the river mainly flow through Gusu District and Wuzhong District of Suzhou that has a high urbanization ratio, mostly construction land, predominantly secondary and tertiary industries, high population density, a high proportion of construction land, less distribution of forest land, grassland, and water, and unreasonable land use. The downstream flowing area is surrounded by more agricultural land, forest land, and water areas, and the nature of land use is less complicated.

Water quality survey sampling

Before and after this study, two water quality sampling surveys were conducted in the suburban and urban areas. The first study selected the junction of the Grand Canal and the Taipu River, the Wujiang Canal Culture Park, and the Baodai Bridge in the suburban section. This provided a total of eight sampling points. The second study selected the Shantang Street and Hanshan Temple in the urban area with five sampling points. The two studies were conducted in November and December 2021 during winter. This was the sensitive period for canal

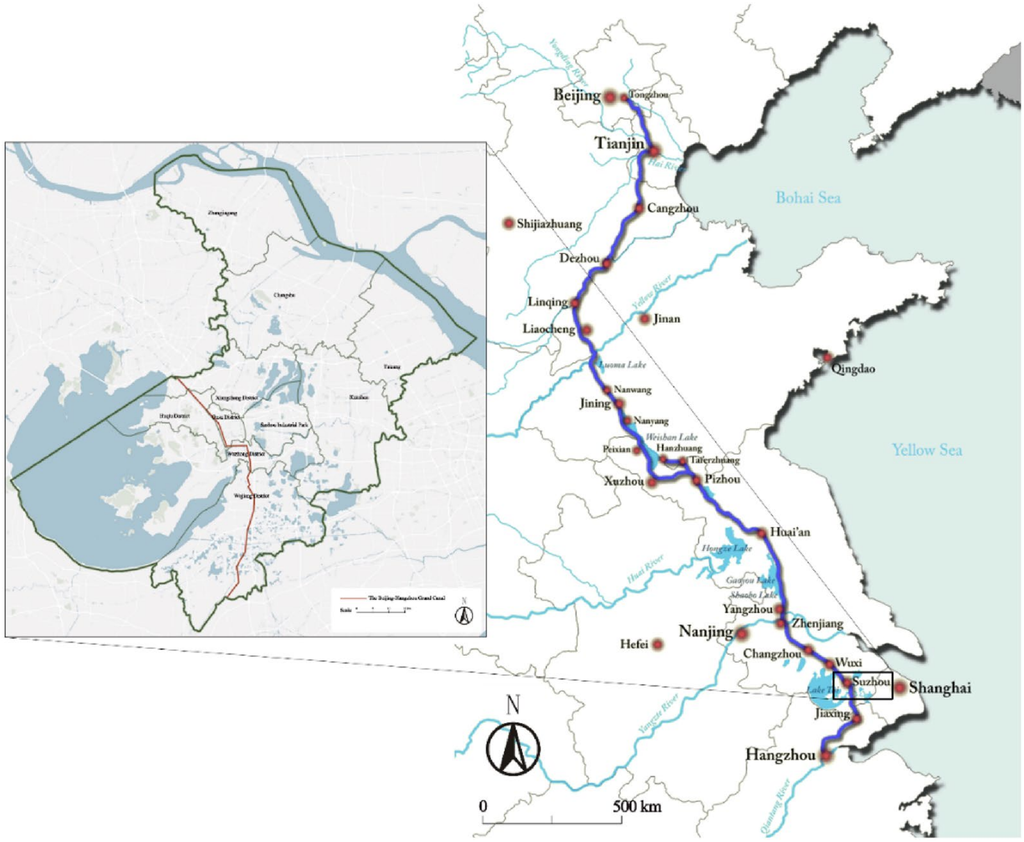

Fig. 3 Geographical location map of Suzhou section of the Beijing-Hangzhou Grand Canal. The Suzhou section of the Beijing-Hangzhou Grand Canal has a total length of about 95 km (the length of the ancient canal south of the Taipu River is about 13 km). Suzhou is one of the birthplaces of the Beijing-Hangzhou Grand Canal, and it is also the only city along the canal to apply for inscription with the "concept of the ancient city," which presents a unique urban historical and cultural landscape of the Grand Canal

water quality when water temperatures are low and dissolved oxygen saturation will be high reflecting the safety condition of the water ecosystem of the Grand Canal (Suzhou section). The locations of the monitoring points are shown in Fig. 4, and the specific sampling time and point coordinates of the Grand Canal (Suzhou section) are given in Table 2. In considering the conditions of the Grand Canal and the feasibility of the research, based on the principles of science, practicality, and evaluability, water quality was adopted as the index for the water ecological safety assessment of the Grand Canal (Suzhou section) [12]. The eight indexes of chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), pH, ammonia nitrogen (NH3-H), conductivity, nitrate nitrogen, and dissolved oxygen (DO) were selected as water quality monitoring data (Table 2), and the data were obtained through sampling survey. The selection of water quality monitoring indicators was mainly based on the five conventional parameters for surface water quality monitoring and the nutrient status evaluation indicators of water bodies in "Environmental Quality Standards for Surface Water" (GB3838-2002), which can comprehensively reflect the degree of pollution in the water bodies of the Grand Canal (including organic pollution, heavy metal pollution, nutrient pollution such as nitrogen and phosphorus, etc.), and representatively reflect the current status of the water quality of the Grand Canal.

Spatial data analysis and modeling

Image pre-processing and remote sensing image interpretation

In this study, Landsat 8 remote sensing images covering Suzhou City in 2019 (https://landsatlook.usgs.gov/explore, acquired on Dec 18, 2022) were selected for supervised classification in remote sensing software ERDASIMAGINE (8.6). Aerial images and field survey results as well as training samples were selected on the images. Supervised classification was performed using the Maximum Likelihood method provided by the software. Classification results were combined, and land use types were classified into six categories concerning the primary land classification system and the

Fig. 4 Location map of ecological monitoring points in the Suzhou section of the Beijing-Hangzhou Grand Canal. Sampling points A to E correspond to the upstream to downstream of the Suzhou section of the Grand Canal. Point A is located at the junction of the Beijing-Hangzhou Grand Canal and the Taipu River, and the surrounding land use is mainly farmland and green land. Point B is located at the Canal Culture Park in Wujiang, and the surrounding land use is primarily commercial industrial land use and green land. Point C is located near the Baodai Bridge, and the surrounding land use is similar to that in Point B. Point D is located near Shantang Street. The surrounding land use is identical to that in points B and C. Point E is located near the Hanshan (Cold-Mountain) Temple, and the surrounding land use is mainly commercial and industrial land use and residential land

distribution of land use in the study area: green land, water bodies, bare land, cultivated land, commercial and industrial, and mining land, and residential land.

At the same time, the methods of UAV image shooting and field research were combined to further complete the identification of vegetation buffer zones within the 0–500 m buffer zone at the monitoring locations of the Beijing-Hangzhou Grand Canal (Suzhou section) based on the results of remote sensing image interpretation to form the research image dataset.

Spatial analysis of buffer zones based on remote sensing and GIS

To study the influence of land use structure and pattern on water quality in different spatial ranges on both banks of the Beijing-Hangzhou Grand Canal (Suzhou section), the composition of land use structure and landscape pattern indices in buffer zones of different distances on both banks of the river were calculated by using the spatial analysis function of buffer zones in GIS. Combined with the land use pattern and spatial distribution on both

Table 2 Water Quality Monitoring Data of Beijing-Hangzhou Grand Canal (Suzhou Section)

Site	Coordinates	Date	COD	TN	TP	PH	NH3-N	Electrical conductivity	DO	Nitrate nitrogen
A1	120°38′54″E, 31°0′14″N	2021.11.13	22	1.33	0.137	6.9	0.607	420	6.6	0.775
A2	120°39′49″E, 31°4′28″N	2021.11.13	27	1.07	0.137	7.0	0.666	373	8.8	0.485
B1	120°39′21″E, 31°8′56″N	2021.11.13	27	1.39	0.175	6.9	0.660	430	8.3	1.04
B2	120°39′43″E, 31°8′37″N	2021.11.13	26	1.57	0.185	6.9	0.610	411	8.1	1.19
B3	120°39′43″E, 31°8′25″N	2021.11.13	37	0.386	0.168	7.1	0.186	303	9.8	0.134
B4	120°39′43″E, 31°8′24″N	2021.11.13	25	1.66	0.213	6.9	0.581	467	8.3	1.27
C1	120°38′31″E, 31°15′42″N	2021.11.13	36	1.92	0.226	6.9	1.20	401	8.5	0.609
C2	120°38′59″E, 31°15′25″N	2021.11.13	29	1.889	0.24	6.9	0.905	442	8.7	0.837
D1	120°33′11″E, 31°19′49″N	2021.12.10	51	2.62	0.308	7.0	0.790	621	2.43	5.6
D2	120°34′25″E, 31°20′6″N	2021.12.10	27	2.49	0.104	7.0	0.551	599	2.04	4.4
E1	120°34′0″E, 31°18′47″N	2021.12.10	59	2.85	0.111	7.0	0.941	687	2.31	6.5
E2	120°33′44″E, 31°18′42″N	2021.12.10	52	2.10	0.209	7.0	0.483	584	2.10	5.8
E3	120°33′51″E, 31°18′32″N	2021.12.10	71	2.12	0.281	7.0	0.468	582	2.02	5.9

(Unit: mg/L). The results of indicators such as conductivity are displayed by converting commonly used units of test results to mg/L for statistical analysis in uniform units

sides of the river from the field survey, five levels of buffer zones were generated with 100, 200, 300, 400, and 500 m radii selected as the circle center of each monitoring section for area statistics. Finally, each monitoring section's land use classification map was obtained (Fig. 5).

Date analysis

In order to study the influence of land use structure and landscape pattern within different buffer distances on both sides of the Beijing-Hangzhou Grand Canal (Suzhou section) on the quality of the water body, the Pearson correlation analysis function in the SPSS software was used to correlate the composition of the land use structure and landscape pattern indices in the buffer zones at different distances on both sides of the canal calculated in 3.2 with the water quality monitoring data and to obtain the correlation with the water quality of the Grand Canal based on the significance judgement factors and influencing mechanisms that are closely related to the water quality of the Grand Canal.

Web-based evaluation data acquisition and processing

(1) Data Acquisition and Preprocessing: The Fengqiao Scenic Spot, one of the famous historical and cultural scenic spots along the coast that overlaps with the water quality survey sites of the Beijing-Hangzhou Grand Canal, was selected for the study. The study chose Ctrip.com and Weibo as data sources. These websites are more prevalent in China, and they all display information such as user name, comment content, date of posting, pictures, etc. The data structure is similar, which makes it easy to be processed. The researcher searched the websites with the keyword "Suzhou Fengqiao Scenic Spot" and obtained 1832 data pieces, which included information fields such as park name, rating (grade), comment content, and comment time. The study data was collected on July 14, 2023, for information collection, spanning from October 19, 2015, to July 11, 2023. Online comment data are usually characterized by fragmentation, categorization, and heterogeneity; irrelevant data must be eliminated. Therefore, the study introduced Python's Jieba participle library tool to solve the problem of solid splitting of professional nouns after removing irrelevant information and de-weighting. Subsequently, word frequency analysis was performed on the participles, and considering the number of participles and word frequency values, participles with word frequency greater than two were defined as high-frequency CES-aware words [28]. Finally, the high-frequency CES-aware words of each park were sorted by word frequency, and the word cloud tool "Micro Word Cloud" was used to describe the result (Fig. 6).

(2) Selection of CES indicators and development of coding criteria: nine service categories of spiritual values, aesthetics, recreation, inspiration, sense of place, cultural heritage, education and knowledge systems, social relations, and negative CES (Table 3) were screened to code the CES indicators, and the connotations of the indicators and the coding criteria were interpreted [27].

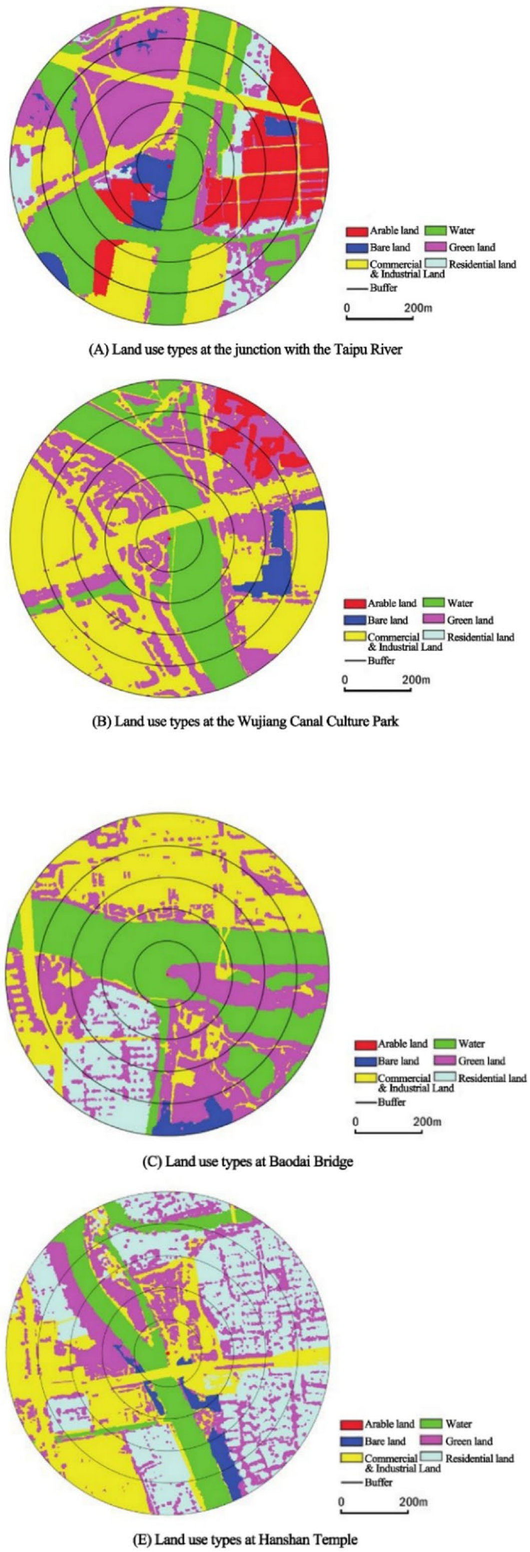

Fig. 5 Land use classification map of monitoring section. The red-colored blocks on the map represent arable land; the green-colored blocks represent waters; the dark blue-colored blocks represent bare land; the purple-colored blocks represent green land; the yellow-colored blocks represent commercial industrial land; and the light blue-colored blocks represent residential land

(3) Classification and coding of CES-perceived words: Classification completes the coding of all comment content, and terms with CES-perceived significance are included in the Perceived Words Database, and meaningless words are included in the Filtered Words Database.
(4) Thematic Analysis: Thematic analysis is an approach to accessing qualitative research data [29]. We used thematic analysis and thematic networks to assess the impact of the water environmental quality of the Beijing-Hangzhou Grand Canal on the perception of the CES [30, 31]. Analysis proceeded through six primary phases: familiarization with the data, coding, searching for themes, reviewing themes, generating thematic networks to create a visual representation of themes, and writing up (Fig. 7). We examined the web review database for content that was important or meaningful to the reviewer and related to themes found in other web reviews. In turn, the data for phase 1 was coded, with initial codes generated based on our initial research, pre-research, and conceptual framework derivations. The code was first fitted into a pre-existing coding framework to provide a detailed analysis of the aspects of the data we were most interested in [32]. After the initial coding was collated, all potentially relevant coded data was extracted into themes using deductive analysis. In turn, the coded data extracts for each piece were reviewed to consider whether they formed a coherent pattern. The validity of individual themes was also fully considered to determine whether the themes accurately reflected the meaning evident throughout the dataset [33]. After completing the thematic review, we analyzed each term of an individual theme in detail, identifying the story each theme tells and ultimately generating the entire thematic network and parsing that thematic network through the text.

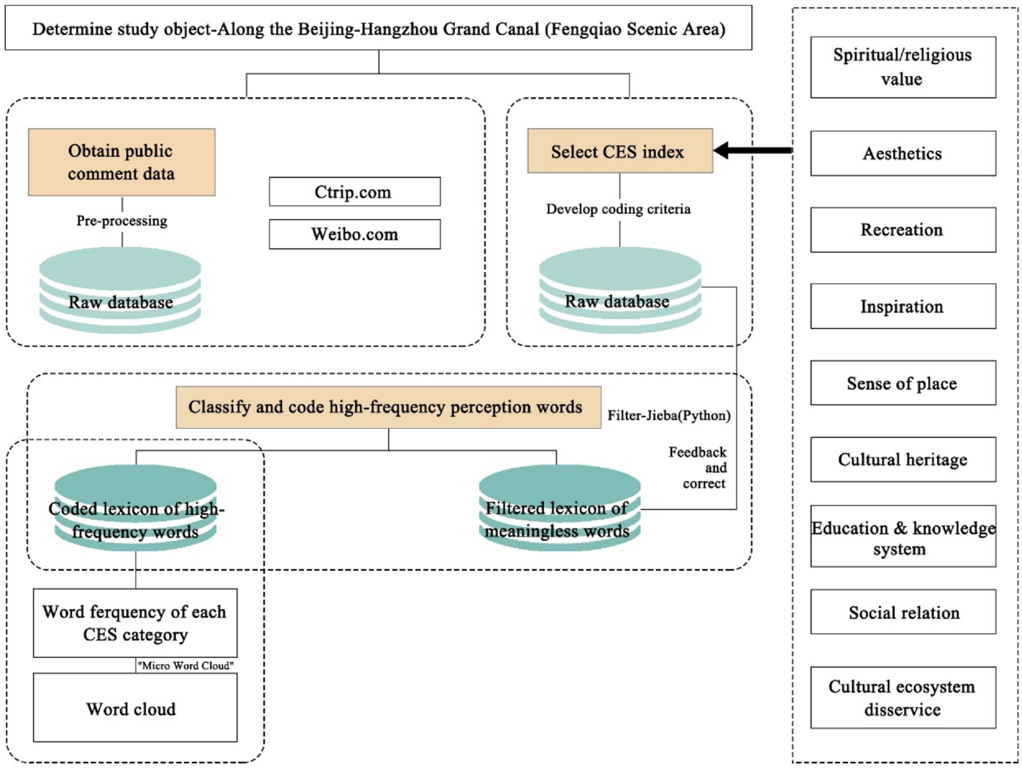

Fig. 6 Flowchart of network assessment data acquisition and data analysis

Table 3 Indicator categories of cultural ecosystem services and coding standards

CES category	Code	Indicators connotation	Coding criteria
Spiritual/religious values	C1	Spiritual, religious, and other values related to solemn activities offered	Religious beliefs or landscape features can provide human beings with objectifying contexts on a spiritual level
Aesthetics	C2	Pleasant visual sensations from viewing the beautiful scenery	Enjoy the beautiful scenery
Recreation	C3	Conducting leisure and recreational activities	Conducting recreational activities (e.g., ecotourism, fishing, and other outdoor recreational activities)
Inspiration	C4	Art inspired by the landscape	The view is associated with poems, paintings, and other art or literary figures
Sense of place	C5	Attachment to a particular place	Mention special experiences or feelings about the scene
Cultural heritage	C6	Cultural and historical values	References to historic buildings, cultural facilities, and regional culture
Education and knowledge system	C7	Knowledge popularization and educational opportunities for the public	Gain knowledge from or describe the park's science facilities
Social relation	C8	Interpersonal social interactions that occur	References to interactions with others or group activities
Cultural ecosystem disservice	ES-	Ecological services that are detrimental to human well-being	Negative evaluation

Results

The land use data for 2019 was analyzed using ArcGIS, and then the land use structure and landscape pattern index of the buffer zone along the Beijing-Hangzhou Grand Canal was obtained, as shown in Table 4 and Fig. 5. We used the correlation analysis between the spatial analysis of the buffer zone of the land use data and the water quality data. It was found that the closer to

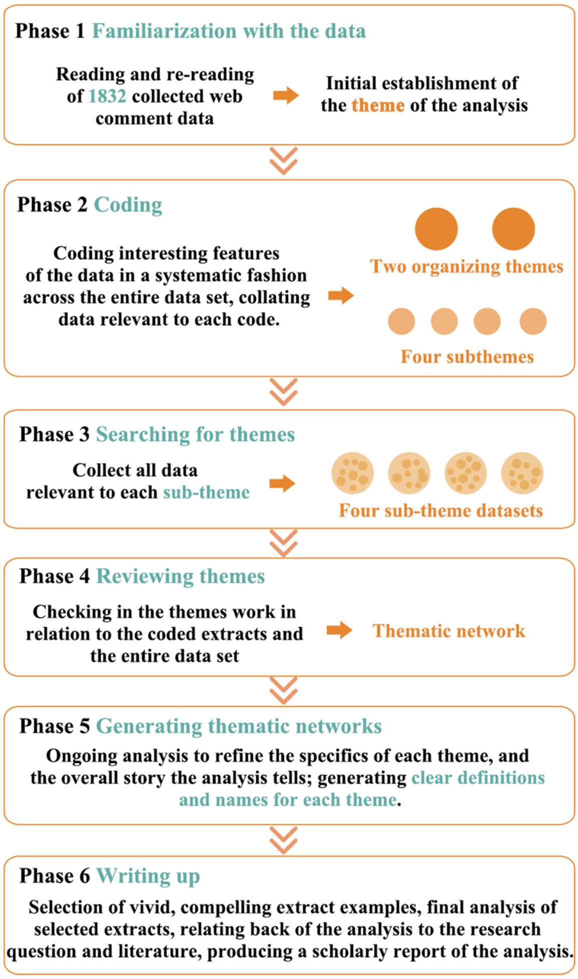

Fig. 7 Thematic Analysis Flowchart. Analysis proceeded through six phases: familiarization with the data, coding, searching for themes, reviewing themes, generating thematic networks to create a visual representation of themes, and writing up

the river, the closer the relationship between the land use structure, the landscape pattern and the water environment, and the greater the impact on water quality, as shown in Table 7. It was also found that impervious urban land was closely related to organic pollution, while green space can effectively reduce river pollution, as shown in Fig. 8. In using content analysis and thematic analysis, it was found that the perceived positive and negative aspects of the cultural services of the ecosystems along the Beijing-Hangzhou Grand Canal were closely related to the quality of the water environment and green space, as shown in Fig. 10.

Land-use structure and landscape pattern

Land-use structure

The land-use structure of the five typical sections of the Beijing-Hangzhou Grand Canal (Suzhou section) on both sides of the river (Table 4), the spatial distribution characteristics can be seen in Table 4: within the study area (calculated with the maximum buffer zone distance of 500 m), the proportion of commercial and industrial land was the highest, and the proportion of the sum of commercial and industrial land and residential land was over 60.0%. The proportion of commercial and industrial land around the Wujiang Canal Culture Park was the highest, at 45.0%, while the proportion of commercial and industrial land at the junction of the Beijing-Hangzhou Grand Canal and the Tai Pu River was the lowest, at 21.0%. The highest proportion of commercial and industrial land wass 45.0%, while the lowest proportion of commercial and industrial land was 21.0% at the junction of the Beijing-Hangzhou Grand Canal and the Taipu River; the highest proportion of residential land was around the Hanshan Temple, 35.2%, while there is no residential land within the study area on both sides of the Wujiang Canal Culture Park; among all the study areas, arable land occupies the minor area, and only arable land exists around the junction of the Taipu River and the Wujiang Canal Culture Park. The proportion of green land in different locations varies little, and the overall proportion can reach 25.0–40.0%. As the distance of the buffer zone increased, the number of each land use type waxed and waned, but the land use structure remained the same, i.e., commercial and industrial land and green land still dominated. This was followed by water bodies and residential land, and the least distributed were bare land and arable land.

Landscape pattern

The spatial variation of the landscape pattern in each section is shown in Fig. 8. The landscape diversity index was highest at the junction with Taipu River and lower near the Wujiang Canal Culture Park and Baodai Bridge Park. When the buffer distance is 100–500 m, the landscape diversity index in descending order was the junction with Taipu River, Hanshan Temple, Shantang Street, Baodai Bridge, and Ancient Fibers Road Park. However, when the buffer distance was within 100 m, the landscape diversity index around the canal in the Baodai Bridge section was the lowest, followed by Wujiang Canal Culture Park. The spatial variation of the landscape dominance index was opposite to the landscape diversity index. The landscape dominance index was highest at the Ancient Fibrous Road Park and lower near the junction of Taipu River. When the buffer distance was 100–500 m, the landscape dominance index was in the order of Ancient Fibrous Road Park, Baodai Bridge, Shantang Street, Hanshan Temple, and the junction with Taipu River. However, when the buffer distance was within 100 m, the landscape dominance index at Baodai Bridge was much higher than

Table 4 Land use structure of different distance buffer zones

Site	Buffer distance (m)	Water (%)	Bare ground (%)	Arable land (%)	Green land (%)	Commercial & industrial land (%)	Residential land (%)	Typical urban land (%)
A. Junction with Taipu River	500	28.3	5.0	15.8	25.5	21.0	7.2	28.2
	400	29.1	5.8	16.0	26.5	20.3	5.3	25.6
	300	30.8	7.8	16.0	28.5	15.3	4.8	20.1
	200	30.7	16.6	13.1	28.3	11.5	3.9	15.4
	100	45.7	32.1	2.0	15.7	10.4	0.0	10.4
B. Wujiang Canal Culture Park	500	20.4	28.5	39.6	29.8	45.0	0.0	45.0
	400	23.2	3.8	2.5	32.3	40.1	0.0	40.1
	300	29.4	0.6	0.0	34.3	37.5	0.0	37.5
	200	40.0	0.0	0.0	27.9	35.2	0.0	35.2
	100	42.7	0.0	0.0	27.3	36.2	0.0	36.2
C. Baodai Bridge	500	26.2	2.0	0.0	31.3	31.9	11.2	43.1
	400	32.2	0.1	0.0	31.6	26.8	11.3	38.1
	300	38.9	0.0	0.0	31.5	20.6	12.3	32.9
	200	55.0	0.0	0.0	28.7	9.0	11.6	20.6
	100	80.0	0.0	0.0	21.2	1.4	0.0	1.4
D. Shantang Street	500	4.9	26.8	0.0	39.2	28.3	6.8	35.2
	400	5.1	25.7	0.0	40.3	29.1	5.5	34.7
	300	6.2	24.7	0.0	39.1	32.5	4.1	36.6
	200	7.3	19.3	0.0	39.8	36.5	1.7	38.2
	100	12.5	14.3	0.0	45.7	29.5	1.6	31.1
E. Hanshan Temple	500	12.6	10.4	0.0	28.7	27.3	35.2	62.5
	400	13.8	12.7	0.0	29.7	26.6	33.5	60.1
	300	16.0	3.8	0.0	32.1	30.6	20.1	50.7
	200	21.8	6.6	0.0	31.8	37.9	4.2	42.1
	100	33.9	4.6	0.0	18.4	46.7	0.0	46.7

Land use structure refers to the percentage structure of each land use type within the buffer zone at different distances from the sample points along the Beijing-Hangzhou Grand Canal

at other points, followed by Wujiang Canal Culture Park. The landscape dominance index at Hanshan Temple was higher than that at Shantang Street. The change in the landscape evenness index was relatively complicated, but the landscape evenness index at the junction with the Taipu River was always the highest. When the buffer distance was 500 m and 400 m, the highest landscape dominance index was at the intersection with Taipu River, followed by Hanshan Temple, Shantang Street, Baodai Bridge, and Wujiang Canal Culture Park. When the distance was 300 m, the landscape evenness around Baodai Bridge dropped sharply to the lowest; when the buffer distance was 200 m, the landscape evenness index dropped to the lowest at Shantang Street, followed by Hanshan Temple, Wujiang Canal Culture Park, and Baodai Bridge. Finally, the highest evenness was at the junction with the Taipu River. When the buffer distance was 100 m, the landscape uniformity index around Baodai

(See figure on next page.)

Fig. 8 Spatial change and comparison of landscape pattern index at different monitoring points. The landscape diversity index reflects the richness and complexity of landscape types, and the larger its value, the richer and more complex the landscape types. The landscape dominance index refers to the degree of landscape structure controlled by one or a few major landscape elements and is an indication of the degree of dominance of a single landscape type; its value is often inversely proportional to the landscape diversity index; the greater the diversity index, the smaller the degree of dominance. The landscape uniformity index reflects the uniformity of the distribution of the area and quantity of each type in the landscape pattern, and the larger its value is, the more uniform the distribution of the size of each landscape type is. Different colors in the bar chart represent other monitoring points, the horizontal axis represents different buffer distances, and the vertical axis represents (**a**) values of the landscape diversity index, **b** values of the landscape dominance index, and **c** values of the landscape evenness index

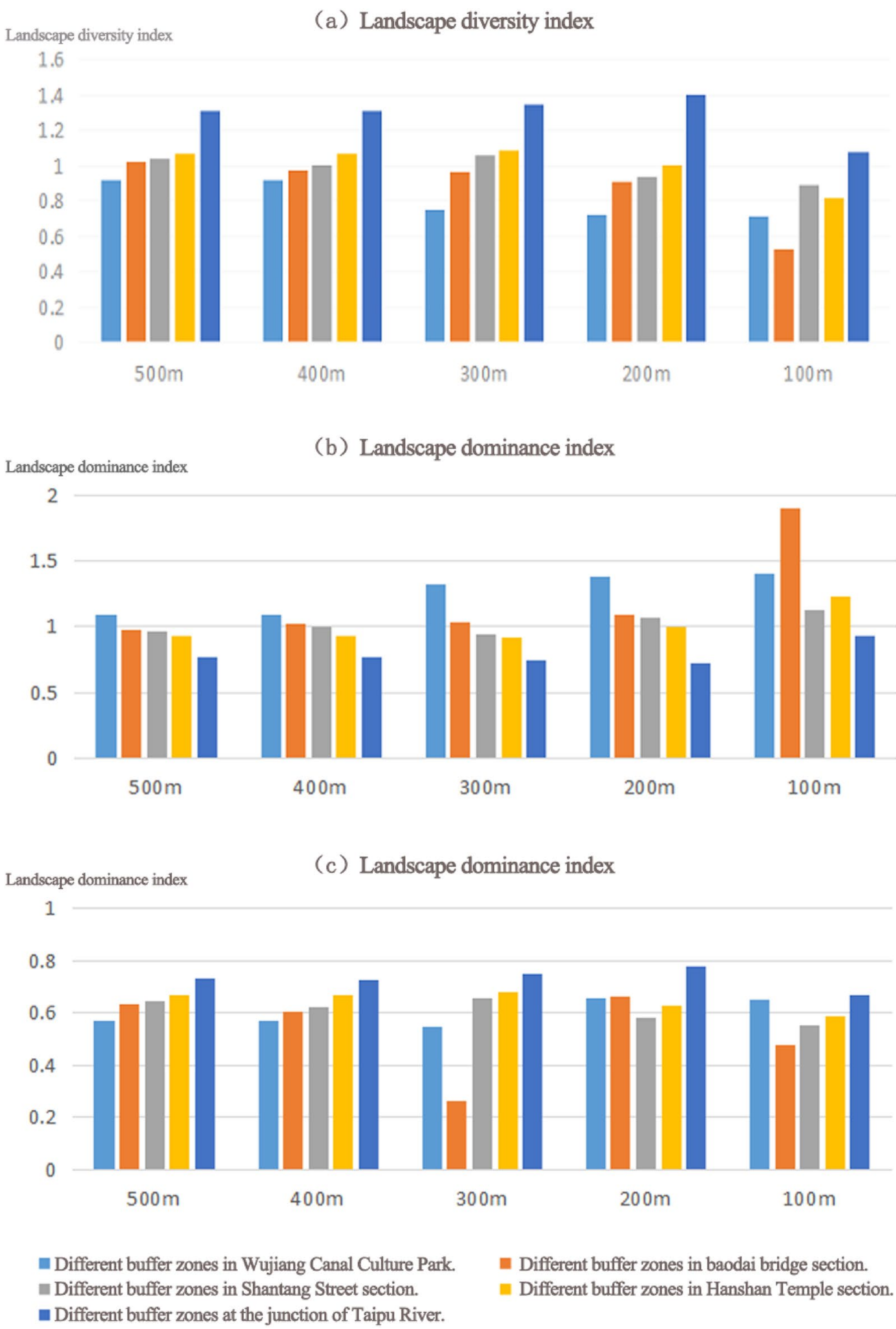

Fig. 8 (See legend on previous page.)

Bridge was the lowest, followed by Shantang Street, and then Hanshan Temple, the junction with Taipu River and Wujiang Canal Culture Park.

The influence of land-use structure on canal water quality

In 2021, the water quality of five key section locations in the upper and middle reaches of the Beijing-Hangzhou Grand

Canal (Suzhou section) was monitored, and two–three sampling points were set up in each vital location (Table 2). The monitoring factors were dissolved oxygen (DO), ammonia nitrogen (NH3-H), chemical oxygen consumption (COD), total nitrogen (TN), total phosphorus (TP), electrical conductivity, nitrate nitrogen, etc. The monitoring results are evaluated by the integrated pollution index method, listed in Table 4, and the evaluation standards are implemented in the "Environmental Quality Standards for Surface Water" (GB3838-2002) for Class IV water quality and the evaluation methods are as follows [34]:

COD, TN, TP, NH3-H single factor pollution indices:

$$P_i = \frac{C_i}{S_i}$$

where: P_i-pollution index of i pollutant; C_i-measured value of i pollutant; S_i-evaluation standard value of i pollutant, mg/L.Combined pollution index:

$$P = \frac{1}{n}\sum_{i=1}^{n} P_i$$

$$K_i = \frac{P_i}{nP} \times 100\%$$

where: P is the comprehensive pollution index of the water body; n is the number of pollution indices participating in the evaluation; K_i is the pollution share of water quality factor i, characterizing the contribution of each pollutant and identifying the primary pollutants; $P_{i,}$ as in the previous paragraph.

Based on the classification criteria in Table 5, the results show that, according to the comprehensive pollution index method, among the five monitoring points, except for points A and B, which reach the qualified standard, C, D, and E all show pollution status. The monitoring points B, C, D, and E are all classified as poor V water due to COD and TN indicators, and the overall water quality of the Suzhou section of the Beijing-Hangzhou Grand Canal is poor (Table 6). The analysis of the main pollution factors and their pollution share shows that the percentage of COD and TN in the five monitoring points is around 30.0–50.0%, and the combined share of the two was more than 60.0%, the most crucial pollution indicator. The five monitoring sites (representing

Table 5 Water-quality Classification: The standard of a comprehensive pollution index

Combined pollution index	Water quality classification	Description of water quality conditions
P < 0.8	Pass	Most items were not detected, and individual detections were within the standard
0.8 ≤ P < 1.0	Basic pass	Individual project detection value exceeds the standard
1.0 ≤ P < 2.0	Pollution	A significant portion of the detected value exceeds the standard
P > 2.0	Severe pollution	A significant portion of the project detection value exceeds the standard several times

Table 6 Water Quality Monitoring Data of the Grand Canal (Suzhou)

Site		COD		TN		TP		PH	NH3-H		EC	DO	NO3-N	Combined pollution index
Standard		**≤ 30**		**≤ 1.5**		**≤ 0.3**		**6–9**	**≤ 1.5**			**0**		
A		27	IV	1.07	IV	0.137	III	7	0.666	III	373	8.8	0.485	Qualified(IV)
	P	0.900		0.713		0.457			0.444					0.628
B		25	IV	1.66	V	0.213	IV	6.9	0.581	III	467	8.3	1.27	Qualified(V)
	P	0.833		1.107		0.710			0.387					0.759
C		36	V	1.92	V	0.226	IV	6.9	1.2	IV	401	8.5	0.609	Pollution(V)
	P	1.200		1.280		0.753			0.800					1.008
D		51	V	2.62	V	0.308	V	7	0.79	III	621	2.43	5.6	Pollution(V)
	P	1.700		1.747		1.027			0.527					1.250
E		71	V	2.12	V	0.281	IV	7	0.468	II	582	2.02	5.9	Pollution(V)
	P	2.367		1.413		0.937			0.312					1.257

(Unit: mg/L). The standards in the table implement the IV water quality standards in the Environmental Quality Standards for Surface Water (GB3838-2002). The calculation and evaluation standards of the P-value and comprehensive pollution index are described above five monitoring areas) are typical of oxygen-consuming organic and nitrogen pollution.

The correlations between the proportion of land use types in different buffer zones and the pollution index values are listed in Table 7. When the buffer zone distance was 100 m and 200 m, the green land in the land use structure showed negative correlations with the indices of COD, DO, and NH3-H, with the correlation with COD reaching a highly significant level at the buffer zone of 200 m (r=− 0.973). This indicated that as the area of this type of land use type increases, there was a significant decreasing trend in the degree of organic pollution in the river. Green land was a buffer zone for urban surface runoff and a natural filter for sediments and their attached nutrients and pollutants, which can absorb some of the nutrients in surface runoff, reduce the amount of surface runoff discharged directly into rivers, and retain some of the sediments and pollutants in surface runoff through a combination of plant absorption, soil retention, and microbial degradation [35]. Based on the analysis of the results, the organic pollution index of rivers showed a significant negative correlation with green land. Therefore, green land can play an essential role in urban land development and construction as a buffer zone and filter for sediments and their attached nutrients and pollutants and should be given special attention.

As seen from Table 7, the cultivated land within 100–300 m of the buffer zone did not show significant correlation with the eutrophic substances TP and TN. This indicated that the cultivated land in the Beijing-Hangzhou Grand Canal (Suzhou section) may not have much relationship with TP and TN pollution in the river which may be related to the fact that cultivated land along the coastline and the vegetation buffer zones constructed between the Beijing-Hangzhou Grand Canal have played a specific purification role. As a separate land use type, the relationship between bare land and water quality also showed the same trend as that of cropland, and its

Table 7 Correlation coefficients between pollutant indexes and land use structure and pattern

Item	Buffer(m)	DO	COD	TN	TP	NH3-H	Electrical conductivity	Nitrate nitrogen
Green land	100	− 0.811	− 0.549	0.845	0.808	− 0.081	0.870	0.811
	200	**− 0.961****	**− 0.973****	0.647	0.759	− 0.474	0.856	**0.956***
	300	− 0.762	**− 0.904***	0.372	0.534	− 0.569	0.622	0.760
Bare land	100	− 0.571	0.307	0.404	0.348	− 0.156	0.542	0.560
	200	− 0.843	0.722	0.461	0.504	− 0.440	0.721	0.830
	300	− 0.865	0.658	0.652	0.655	− 0.299	0.822	0.857
Arable land	100	0.450	− 0.437	− 0.789	− 0.809	− 0.149	− 0.592	− 0.467
	200	0.450	− 0.437	− 0.789	− 0.809	− 0.149	− 0.592	− 0.467
	300	0.450	− 0.437	− 0.789	− 0.809	− 0.149	− 0.592	− 0.467
Commercial, industrial, & mining land,	100	**− 0.961****	**0.930***	0.654	0.773	− 0.563	**0.900***	**0.967****
	200	− 0.829	**0.905***	0.462	0.621	− 0.626	0.733	0.836
	300	− 0.712	0.855	0.352	0.523	− 0.597	0.603	0.718
Residential land	100	− 0.578	0.262	0.724	0.632	0.097	0.676	0.578
	200	− 0.652	**0.894***	0.443	0.526	− 0.030	0.431	0.615
	300	− 0.672	**0.885***	00.295	0.449	− 0.445	0.489	0.660
Typical urban land	100	**− 0.969****	**0.926***	0.672	0.786	− 0.551	**0.913***	**0.975****
	200	− 0.830	**0.926***	0.471	0.626	–0.579	0.720	0.833
	300	− 0.702	0.876	0.331	0.497	− 0.539	0.561	0.700
Landscape diversity	100	− 0.176	0.016	− 0.309	− 0.282	− 0.576	0.084	0.178
	200	0.135	− 0.060	− 0.545	− 0.554	− 0.105	− 0.371	− 0.172
	300	− 0.083	0.140	− 0.329	− 0.340	− 0.093	− 0.168	0.040
Landscape superiority	100	0.318	− 0.124	0.181	0.127	0.719	− 0.264	− 0.331
	200	0.031	− 0.130	0.362	0.374	0.029	0.235	0.016
	300	0.215	− 0.289	0.157	0.173	0.008	0.051	− 0.165
Landscape evenness	100	0.202	− 0.323	− 0.618	− 0.528	− 0.787	− 0.166	− 0.162
	200	0.731	− 0.615	**− 0.964****	**− 0.972****	− 0.038	− 0.848	− 0.743
	300	− 0.400	0.234	− 0.140	− 0.057	− 0.813	0.339	0.417

* Denotes significant correlation at the 0.05 level, ** indicates highly substantial correlation at the 0.01 level (confidence level = 95%) Bolded format number indicates that is statistically correlated

correlation with TP and TN was insignificant. The area of arable land and bare land within the buffer distance of 0–300 m along the Beijing-Hangzhou Grand Canal (Suzhou section) was relatively small. Vegetation buffer strips were set up between arable land and bare land and the Grand Canal in many places (Fig. 9), so the close communication with the river needed to be stronger. The pollution impact on the river was small, which confirmed the results of this study.

The two most crucial pollution-exporting land use types in the urban land use structure, commercial industrial land, and residential land, which are the products of the rapid urbanization process, dominated in quantity and area ratio. As seen from Table 7, commercial and industrial land use showed a significant correlation with COD and a highly significant correlation with nitrate-nitrogen when the buffer zone distance was 0–100 m, and residential land use show a substantial correlation with TN. In combining the two into a typical urban site, we can see from the statistical results that the specific urban area significantly correlates with COD and nitrate–N and had a slightly weaker correlation with TP Pollution.

The influence of landscape pattern on canal water quality

Table 7 shows, the landscape diversity index and dominance index in the landscape pattern did not correlate significantly with each pollution index. The landscape evenness index reflected the uniformity of the distribution of each type in the landscape pattern in terms of area and quantity, and the larger its value, the more uniform the distribution of each landscape type in terms of area. In the study, the evenness index showed a highly significant negative correlation with TN ($r = -0.964$) and TP ($r = -0.972$). This indicated that the number of commercial, industrial, and residential lands decreased. The area of land types such as green land and bare land increased, and TN and TP had a decreasing trend. From the perspective of landscape patterns, we can also saw that commercial and industrial land use and residential land use in land-use structures correlated more with urban river water pollution.

The influence of spatial variation of buffer zone distance on correlation

As shown in Table 7, when the buffer zone distance increased from 100 to 200 m, the land use structure and pattern showed a similar correlation with river water quality, but the overall correlation weakened. For example, the significance of commercial, industrial, and mining land with COD and nitrate-nitrogen gradually disappeared when the buffer distance increased; the importance of commercial, industrial, and residential land with COD and nitrate-nitrogen index also gradually disappeared when commercial and, industrial, and residential land is combined into typical urban land; the

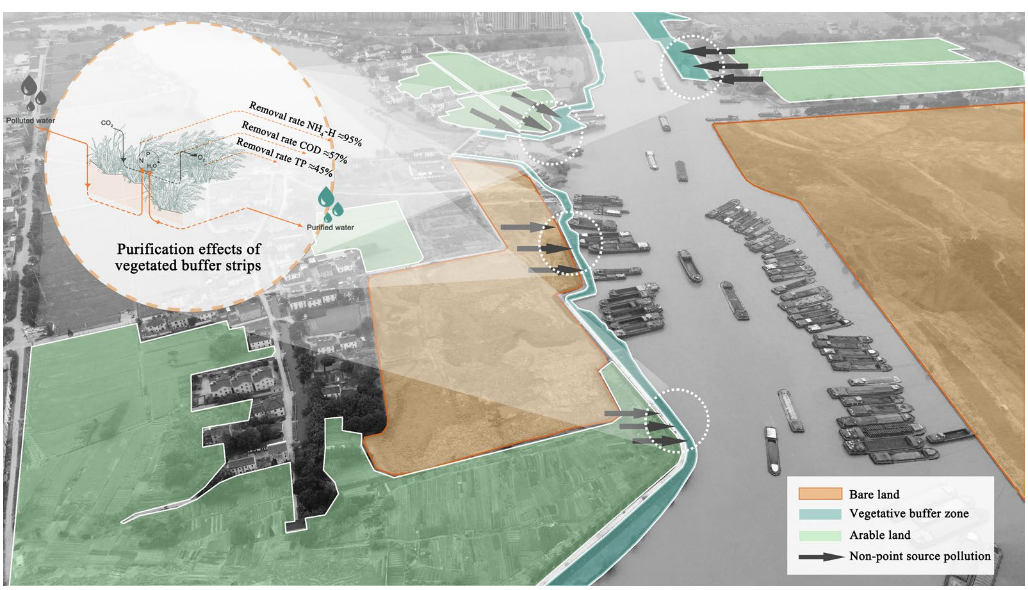

Fig. 9 Schematic diagram of vegetation buffer zone between Beijing-Hangzhou Grand Canal and coastal cultivated land. In the figure, the orange blocks represent bare land, the green blocks represent arable land, the blue-green blocks represent vegetative buffer zones, and the black arrows indicate pollution inputs. The white dotted circle boxes indicate the purification effect of vegetation buffer zones along the Suzhou section of the Beijing-Hangzhou Grand Canal on pollution inputs from arable land/bare land; the upper right corner is a schematic diagram of the principle of sewage purification by vegetation buffer zones

correlation coefficients of other land use types with water quality index also decreased significantly; however, the significance of residential land with COD increased, and the significance of green land with DO, COD, nitrate-nitrogen and other pollution indexes appear with a significant correlation.

When the buffer zone distance increases to 300 m, the correlation exhibited by land use structure and pattern and water quality decreased significantly, and even the significance disappeared. The results showed that a buffer zone range with a spatial distance of 100 m can better present the relationship between land use structure, landscape pattern, and river water quality within the city. It can be inferred that the closer the distance to the Beijing-Hangzhou Grand Canal, the more intimate the relationship between land use structure and pattern and its water environment, and the more prominent the influence on water quality.

The perception of cultural ecosystem services (CES)

Characteristics of public perception of CES along the grand canal

Statistical analysis of word frequency revealed that high-frequency CES-perceived words reflecting aesthetics, leisure/ecotourism, cultural heritage, and inspirational inspiration appeared more frequently in the Fengqiao Scenic Area along the Beijing-Hangzhou Grand Canal. This suggested that these four types of CESs were most likely to be perceived by the public. Among them, the frequency of CES perceptions describing aesthetic preferences such as "good-looking," "very beautiful," and "night view" was high. The public can enjoy the cultural landscape of the Beijing-Hangzhou Grand Canal to get aesthetic satisfaction while reflecting the important aesthetic value of the Grand Canal. CES perceptions relating recreational activities such as "strolling," "taking a boat ride," "touring," and "photographing" were the most prevalent. The frequency of CES perceptions describing inspirations such as "Night Poaching on the Maple Bridge," "Zhang Ji," and "Cold Mountain Monastery outside of Gusu" was high. This embodied a rich ideology as well as an emotion and humanistic spirit. The Grand Canal serves as a medium to disseminate traditional moral values, achieving the function of educating people by osmosis and carrying important educational values. CES perceptions describing cultural heritages such as "Cold Mountain Monastery," "The Grand Canal of Beijing-Hangzhou," and "The Tieling Pass" are the most prevalent, and these historical and architectural cultural heritage and the intangible cultural heritage are in symbiosis and co-mingled and carry the cultural value of the Grand Canal, which has been continuously developed and inherited in the long-term historical period (Fig. 10).

In addition, negative CES, spiritual/religious values, social relations, and education and knowledge systems were also more likely to be perceived by the public. The negative CES perceived by the public was mainly reflected in the perception words such as "regret" and "not worth it," reflecting the gap between public demand and the supply of scenic services. Comments such as "cold" and "not much content" reflected the problem of insufficient services for the aesthetic appreciation of picturesque landscapes. Meanwhile, CES perception words such as "dirty water," "pollution," and "turbidity" were mentioned many times, reflecting that water quality is an essential aspect of public perception. "Exhibition halls," "memorial halls," "museums," "exhibition halls," "museums," "display halls" and other popular science education buildings were mentioned many times; "interpretation," "introduction of allusions," "telling historical stories CES perceptual words such as "explain," "introduce allusions," "tell historical stories," etc. which described the interpretation system were also mentioned many times. The spiritual/religious values perceived by the public are mainly embodied in Buddhism, revolutionary spirit, etc. For example, "fighting against Wokou invaders" and "commemorating liberation" in the CES perceptions reflect revolutionary spirit; "Buddhism," "praying for blessings," "monks," etc. all reflect Buddhist content (Fig. 10). Similar to the results of previous studies, the public perceived Maple Bridge View's sense-of-place services to be generally low [36].

As a recreational destination for residents and foreign tourists, Fengqiao Scenic Area has beautiful scenery. It is rich in historical monuments, cultural facilities, and non-heritage activities with high historical and cultural values, so the public perception of the Fengqiao Scenic Area is vital for its cultural heritage and art-inspired services. By exploring the correlation relationship, it was found that the Beijing-Hangzhou Grand Canal-related perception words were mentioned in aesthetics, recreation, and cultural heritage, and there are perception words such as "dirty," "polluted," "turbid," etc. in the negative CES. The water quality of the Beijing-Hangzhou Grand Canal affects the perception of cultural services of the ecosystems along the canal in many ways.

Thematic analysis—mechanisms of water quality impacts on public perception of CES

To further explore the impact of the quality of the water environment in the Beijing-Hangzhou Grand Canal on the perception of CES, we used thematic analysis to create a thematic network of web databases under this topic to create a visual summary of the rich and complex information obtained from the web comments, as shown in Fig. 11 below.

Fig. 10 Cloud analysis of high-frequency CES sense words in the Maple Bridge landscape. Since the perceptual network data come from Chinese reviews on Chinese websites, the results of this study are presented in the form of Chinese-English translation. Due to cultural differences and language habits, some Chinese reviews use formats such as literary language and ancient poems, and the results of the English translation may be slightly different from the original meaning

The thematic network focuses on two organizing themes, 'Positive' and 'Negative'. The organizing theme "positive" encompasses waterscape experiences that induce positive emotions and aesthetic perceptions. Within this context, we describe a further subtheme, "Aesthetics," which deals with the content related to aesthetic perception in the CES perceptual experience. In terms of aesthetic perception, the Beijing-Hangzhou Grand Canal brings people a sense of historical nostalgia represented by "Simple and unadorned" and "Sense of history," and a sense of shock represented by "Magnificent," "Openness" and "Flourishing." At the same time, there is also a sense of immersion, which presents the ancient scene reproduced first-hand experience.

> *"It was a spectacular sight to see the big cargo ships connected like trains on the Grand Canal today. Thousands of years have passed, the scenery along the banks is changing, and the boats on the river are constantly renewed. The Beijing-Hangzhou Grand Canal still carries the important function of water transport and is full of emotions!"*

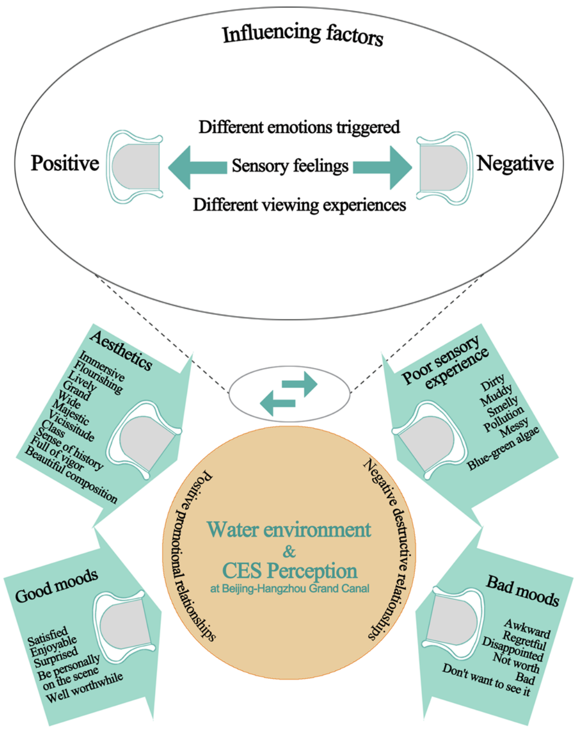

Fig. 11 Cultural Ecosystem Services (CES) Perception Thematic Network. We define the whole theme as a "round table," divided into two "camps," i.e., two organizing themes, according to the data's different sensory feelings, viewing experiences, and emotions. Each "chair" is a sub-theme of an organizing theme, with arrows describing what is contained within the sub-themes

"Experience the mood of the ancients, not for nothing to come back; the family also feels the same way, especially just in the first grade of the child, very excited to be immersed in the "Maple Bridge Night Mooring," Gusu City outside the Cold Mountain Temple, the sound of bells at half past midnight to the passenger boat, the feeling is good!"

We also defined a second subtheme, "Emotional," within the organizing theme, "Positive," which refers to the positive emotional expressions triggered during the CES perceptual experience. Among the inspirational words, reviewers expressed positive emotions such as "Satisfied," "Worthwhile," "Shocked," "Surprised," etc., during the Beijing-Hangzhou Grand Canal water landscape experience.

"With its long history, many ruins, and rich culture, it's worth going for a slow walk!"
"The most surprising thing is that the Beijing-Hangzhou Canal is located here, and seeing the cargo ships coming and going reminds me of the prosperity of canal transport here a thousand years ago."

The second organizing theme in the thematic network was 'Negative,' which we define as negative emotions and sensory experiences due to the poor quality of the water environment. Here again, we delineated two further subthemes. The first was the negative sensory experience induced by poor water quality in the CES perceptual experience, which we call 'Sensory.' Regarding negative sensory experiences, commenters tended to have more impoverished water environments, resulting in poor sensory experiences such as the visual experience of seeing turbid water and the olfactory experience of smelling foul odors emanating from the water.

"The water's too dirty to look at."

The second subtheme, 'Emotional,' refers to the negative emotional expressions induced by the poor quality of the water environment in the CES perceptual experience. In the negative emotional words, commenters tended to have "Regretful," "Disappointed," "Unworthy," and "Bad" emotions as a result of the poor water environment.

"The only pity is that the new river, due to serious water pollution, is now a green and smelly dead river; taking a scenic boat ride must be the feeling of this money paid in vain."

Negative sensory experiences and emotions combine to influence reviewers' overall CES perceptions and hinder the development of an attachment to the landscape experience, reducing the landscape's secondary appeal to reviewers.

By combing the thematic networks and extracting the characteristics of the rich and complex information obtained from the network comments, it was found that water quality affects the public's perception of CES in two main ways. First, it affects the public's sensory perception in the process of experiencing, for example, the public can feel more positive visual feelings such as "spectacular" and "prosperous" during the period of better water quality, while in the period of poorer water quality, the public will preferentially feel the " turbid", "stinky" and other bad visual and olfactory sensations. Second, different psychological emotions are induced, for example, the public is more able to give positive emotional feedbacks such as "satisfied" and "worthwhile" during the period of better water quality, while "regretful" and "disappointed" during the period of poorer water quality are preferred. For example, the public is more likely to give positive feedback such as "satisfied" and "worthwhile" during periods of good water quality, whereas they are more likely to give negative feedback such as "regretful" and "disappointed" during periods of poor water quality.

Discussion

The study found that the closer the buffer zone was to the Beijing-Hangzhou Grand Canal, the closer its land use structure and landscape pattern were to the water environment, and the more significant the impact on water quality. Green spaces were essential in effectively reducing the effects of anthropogenic disturbances, such as pollution. They were a crucial point for ecosystem management along the Beijing-Hangzhou Grand Canal. At the same time, with the passage of time and the increase of pollution sources, the Beijing-Hangzhou Grand Canal also facies potential ecological risks, mainly due to the pollution from typical urban land. Hence, identifying risk sources and an early warning intelligence system is essential for protecting and managing the Beijing-Hangzhou Grand Canal. As a world cultural heritage, the ecosystem and cultural services of the Beijing-Hangzhou Grand Canal are also a critical part of protecting and conserving its cultural and artistic values. The results of the CES perception study showed the water quality condition of the Beijing-Hangzhou Grand Canal plays a pivotal role in the provision of ecosystem and cultural services, and the current ecosystem and cultural services of the Beijing-Hangzhou Grand Canal along the shoreline still needs to be optimized further.

Strategies for optimizing ecosystem services of green spaces and water quality

(i) Optimization strategies for water quality protection

First, water quality protection begins with the establishment of an intelligent system for the identification of potential sources of risk and early warning. Early warning captures changes in ecosystem structure and properties before crucial inflection points (or threshold points that define shifts in system state) [37]. The emergence of unmanned aerial vehicles (UAV) can help the relevant staff to monitor and early warning of changes in the water environment and identify potential sources of risk instead of the traditional cruise monitoring work. Once a certain degree of change in the water environment occurs, UAVs can be located faster and more accurate early warning to help staff find the source and control as soon as possible [38]. The IoT joint control and coordination system platform can guarantee its operation [39]. Its forecasting and scheduling sub-system make use of the system-shared information source to manage the real-time water and rain situation, working condition, water quality, and video information collected by the monitoring system and combine with the need for collaborative decision management to monitor and evaluate the water and rain situation, water environment, project operation condition and spatial and temporal distribution in the region in real-time. Combined with GIS, GPS, intelligent perception, and other new technology, its joint regulation and control visualization business services support various handheld intelligent operating systems (Android, iOS), custom development of cross-platform mobile integrated business application systems (smartphone apps, WeChat), providing a convenient and fast mobile business information processing platform anytime, anywhere, forming service automation, office networking, management scientific, supervision information mobile water management functions [40].

Second, the results indicate that improper land use structure and management can lead to surface pollution in the watershed and cause deterioration of water quality. Therefore, reasonable land use planning is essential in urban ecological development. With the development of science and technology, it has been proposed that coupling CLUE-S with the SWAT model in land use planning can simulate and quantitatively evaluate nitrogen and phosphorus loads under different land use scenarios and predict the effect of nonpoint source pollution control under additional optimal land use planning and assumptions [41]. The land use simulation model CLUE-S can predict and simulate the spatial expression of land change in the short term through regression relationships between historical land patterns and driving forces [42]. The SWAT model is used to predict the effects of land use change and agricultural management practices on water flow, sediment, and water quality in large and complex watersheds [43–45]. The coupled predictions of CLUE-S and the SWAT model will provide a scientific basis for developing more rational land use planning and nitrogen and phosphorus load control (water quality control) strategies [46–48].

Third, the results of both field surveys and statistical analyses indicate that sewage discharge remains a key threat to the water quality of the Grand Canal, with typical urban sites being the main source of pollution input. Therefore, intercepting and connecting the disorganized domestic and agricultural and industrial sewage on both sides of the Beijing-Hangzhou Grand Canal and integrating the sewage discharged into the river into the urban sewage network is the top priority to control the pollution output from typical urban land. Particular attention should be paid to areas such as villages and development zones (refers to undeveloped place which has the potential for economic or human environment), where domestic sewage treatment lags behind that of urban areas and the domestic sewage treatment system is not yet complete, and unused land such as bare land in the area is often developed into small pieces of farmland by nearby residents. There is a risk of surface source pollution, and such areas should be prioritized for investigation, management, and supervision.

(ii) Optimizing and enhancing the size and quality of green spaces

Existing riparian buffers should be targeted for revegetation and optimization of vegetation structure. Green land has a significant role in mitigating the organic pollution of rivers, especially within 100 m of the green buffer zone, so the role of green land as a pollution buffer and filter in urban construction should be emphasized. Priority should be given to restoring vegetation in the buffer zone close to the river bank and then extending inland to restore vegetation to optimize the vegetation structure of the river bank buffer zone. Riparian Ecosystem Management Model (REMM) and River-vegetation Mathematical Models can help to simulate the expected changes in riparian vegetation in restoration scenarios and to continuously improve restoration scenarios by simulating changes in the morphodynamics associated with the interaction of river and riparian vegetation under different hydrological regimes [49, 50]. Terrestrial vegetation restoration should follow the plant configuration pattern of combining trees, shrubs, and grasses. The restoration of aquatic vegetation should follow the combination principle of "water-holding plants—floating plants—floating plants—submerged plants" (to ensure the unique navigable nature of the Beijing-Hangzhou Grand Canal, the restoration of aquatic vegetation should be carried out in the tributaries and other waters connected to it or in the form of recessed into the land, without infringing on the waterway). To ensure the unique navigable nature of the Beijing-Hangzhou Grand Canal, aquatic vegetation should be restored in its connected tributaries and other waters or the form of landward depressions without infringing on the waterway. The perceptions of CES along the Beijing-Hangzhou Grand Canal are associated with the public's opinions on its cultural heritage services and artistic inspiration services. The perceptions of CES are closely related to the quality of the water environment and riparian greenness which affect the values of cultural heritage and conservation of the Beijing-Hangzhou Grand Canal.

At the same time, unused land should be used rationally to create temporary greening and subsidize the overall greening area. For example, temporary greening of bare land before its development and construction can help reduce the pollution output of this land type to the river. This quick greening often requires little investment in human planning and disturbance, but it establishes a specific ecological background in the area and helps it undergo natural succession [51].

The optimization of cultural ecosystem services (CES)

Based on the results of this study, water quality enhancement and cultural heritage protection have always been the basis and essential link in the protection and development of the Beijing-Hangzhou Grand Canal as well as an effective means of improving the perceived aesthetics and passing on the historical and cultural aspects of CES supply. Modern landscape techniques can translate traditional historical and cultural elements, activate their vitality and charm in contemporary life, reconstruct the spatial narrative structure of humanistic landscapes in parks, and strengthen the interaction between the public and history. In addition, while meeting the public's needs for history, culture, and artistic aesthetics, it can also satisfy the diversified needs of all-time and all-age and strengthen the park's leisure/ecotourism services [52]. At the same time, we should focus on the landscape elements repeatedly mentioned in the word cloud of high-frequency CES perceptions and improve the landscape elements mentioned in negative CES.

Conclusion

The rapid process of industrialization and urbanization impacted the environmental quality of both land and water bodies along the Beijing-Hangzhou Grand Canal. This study assessed the relationship between the canal water quality response to land-use change and the water quality's influence on the perception of cultural ecosystem services, with the aim for strengthening the management of ecological and cultural protection of the Beijing-Hangzhou Grand Canal in addressing environmental challenges [53]. The research methods and results have implications for other research in different river basins of China and other countries.

Land-use type has an essential influence on the water quality of the Beijing-Hangzhou Grand Canal (Suzhou section). With the increase of buffer distance, the correlation between land-use structure and landscape pattern and canal water quality was significantly weakened. Typical urban land with impervious surface is positively correlated with organic pollution and is the primary pollution output land type causing river pollution; while riparian green land can reduce river pollution effectively. The correlation between landscape pattern and water quality better explains the relationship between TN and TP pollution and land use. The main potential ecological risks of the Beijing-Hangzhou Grand Canal (Suzhou section) are identified as cumulative oxygen-depleting organic pollution and nitrogen pollution, which are correlated with its coastal land use structure. Rapid urbanization leads to the expansion of urban land and compression of natural land, which increases the possibility of pollution input from surface runoff to the Grand Canal (Suzhou section). In the conservation and effective protection of the world's historic heritage canals for the "outstanding universal value", attention should be paid to the impact of land-use types and patterns on the water quality [54]. We should plan more green lands on both riparian sides of the canals, strengthen vegetation restoration in the buffer zones, make the full use of unused land by exploring its ecological potential, such as bare land, control the nonpoint-source pollution output of typical urban land, and enhance the capacity of the World Heritage Beijing-Hangzhou Grand Canal in provisioning cultural ecosystem services to cope with ecological risks from anthropogenic activities [55, 56].

On the perception of ecosystem cultural services, through content analysis, it can be found that the public most easily perceives aesthetics, leisure/ecotourism, cultural heritage, and inspiration in the Fengqiao scenic area along the UNESCO World Heritage Beijing-Hangzhou Grand Canal. Its beautiful scenery as a leisure and recreation destination and the abundance of historical monuments, cultural relics and facilities, and non-heritage activities have high historical and cultural values, which are crucial for evaluating management effectiveness [57]. Thus, the public perception of its cultural heritage services and artistic inspiration services are more robust, which is an essential perceptual feature of its ecosystem cultural services [58]. Since poor water quality condition mainly induced negative CES perceptions, its improvement and maintennance at good-quality criteria (level-III) through integral preventive conservation are crucial [59]. Taking this as the theme, in further thematic analyses, the perception of the cultural ecosystem services of the World Heritage Beijing-Hangzhou Grand Canal was closely related to the water quality, by influencing public's sensory perception [60, 61]. On the conservation aspect of the World Heritage Beijing-Hangzhou Grand Canal, it is urgent, through emerging technologies, to increase healthy water quality and riparian greenness, and to reduce potential risks of anthropogenic disturbance for supporting and enhancing its Cultural Ecosystem Services [62].

Acknowledgements

We would like to thank Xindi Zhang, Ting Liu, Zhe Li, Xinge Wang, Mr. Xuerong Ma, Dr. Bo Lu, and Professor Zhaojun Feng for their support in field works and data collection. We thank Dr. Morgan McClure provided helpful comments and editing reading to improve this paper. This work is supported by the National Key R&D Program of China (2021YFE0200100), Suzhou Grand Canal Cultural Zone Construction Research Institute (21SZDYH103), and Suzhou Water Conservation Bureau Research Program (2021002; 2022010).

Author contributions

YZ and ZJ conceived the manuscript structure; YZ developed the conceptual framework; ZJ, YZ wrote the draft; ZJ, YZ, QH, XW, WS prepared tables and figures; YZ, ZJ revised the manuscript; QH, XW, WS, JW, JZ, LT, JSW LZ, BW, LW, XS, JS, WW, YW, AC reviewed the manuscript; YZ, YW received funding.

Funding

National Key R&D Program of China (Grant No. 2021YFE0200100; Suzhou Grand. Canal Cultural Zone Construction Research Institute (Grant No. 21SZDYH103); Suzhou Water. Conservation Bureau Research Program (Grant No. 2021002; 2022010).

Availability of data and materials

The datasets used and analyzed in the current study are available upon reasonable request.

Declarations

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Received: 8 September 2023 Accepted: 26 November 2023
Published online: 19 December 2023

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